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LETTER

Status and Trends in Global Ecosystem Services and Natural Capital: Assessing Progress Toward Aichi Biodiversity Target 14

Ellen Shepherd[1], E.J. Milner-Gulland[1,2,3], Andrew T. Knight[1,3,4], Matthew A. Ling[5], Sarah Darrah[5], Arnout van Soesbergen[5], & Neil D. Burgess[5,6,7]

[1] Department of Life Sciences, Imperial College London, Silwood Park Campus, Buckhurst Road, Ascot, Berkshire SL5 7PY, UK
[2] Department of Zoology, Oxford University, South Parks Road, Oxford, OX1 3PS, UK
[3] ARC Centre of Excellence in Environmental Decisions, The University of Queensland, St. Lucia, QLD 4072, Australia
[4] Department of Botany, Nelson Mandela Metropolitan University, P.O. Box 77000, Port Elizabeth 6031, South Africa
[5] UNEP World Conservation Monitoring Centre, 219 Huntington Road, Cambridge, CB3 0DL, UK
[6] CMEC, The Natural History Museum, University of Copenhagen, Østervoldgade 5-7, DK-1350 Copenhagen K, Denmark, Copenhagen, Denmark
[7] Department of Zoology, University of Cambridge, Cambridge, CB2 3EJ, UK

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Correspondence
Ellen Shepherd, 63G Lewisham Hill, London SE13 7PL, UK.
Tel: +44 7790 569317.
E-mail: ellen.shepherd14@alumni.imperial.ac.uk

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Abstract

The Convention on Biological Diversity uses six indicators to assess progress toward Aichi Biodiversity Target 14 (ecosystem services), leaving many elements of the target untracked. We identify 13 ecosystem services as directly essential for human well-being, and select a set of 21 datasets as indicators of the state of natural capital underpinning those services, the benefits derived from them, and distribution of access to those benefits. Analysis of these indicators supports previous conclusions that there is no overall progress toward Target 14. Sixty percent of our "benefit" indicators have positive trends, whereas 86% of our "state" indicators show a decline in natural capital. This suggests that well-being is increasing in the near-term despite environmental degradation, and that unsustainable use of natural capital may fuel human development. As regulating services such as "soil fertility" continue to decline, however, it seems unlikely that this trend can continue without future negative impacts on humanity.

Introduction

In response to biodiversity declines (Butchart *et al.* 2010) and an increasingly well-understood relationship between biodiversity and human well-being (Mace *et al.* 2012), the Parties to the Convention on Biological Diversity (CBD) adopted the Strategic Plan for Biodiversity 2011–2020 (Strategic Plan), including the 20 Aichi Biodiversity Targets. Human interactions with nature can be framed using the language of natural capital (NC) and ecosystem services (ES; Figure 1). ES contributions to human well-being are complex and sometimes poorly understood (The Economics of Ecosystems and Biodiversity 2010). A growing human population and a shift toward more resource intensive lifestyles are increasing the demands on ES. This appears to be degrading reserves of NC, potentially reducing ES available to future generations (Millennium Ecosystem Assessment 2005).

Global Biodiversity Outlook 4 (GBO-4; Secretariat of the Convention on Biological Diversity 2014), which provided a mid-term assessment of progress toward the Aichi Targets, concluded that, while significant progress had been made toward "some components of the majority of" the targets, generally progress was insufficient to ensure that targets would be met by 2020. GBO-4 was underpinned by sources including statistical analysis of global indicators (Tittensor *et al.* 2014), the 5th National Reports to the CBD, and global indicators compiled by the Biodiversity Indicators Partnership (BIP; Leadley *et al.* 2014).

GBO-4 divided Target 14, which focuses on ES, into two elements: (1) "Ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded . . ."; and, (2) " . . . taking into account the needs of women, indigenous and local communities and the poor and vulnerable." Element one was assessed as

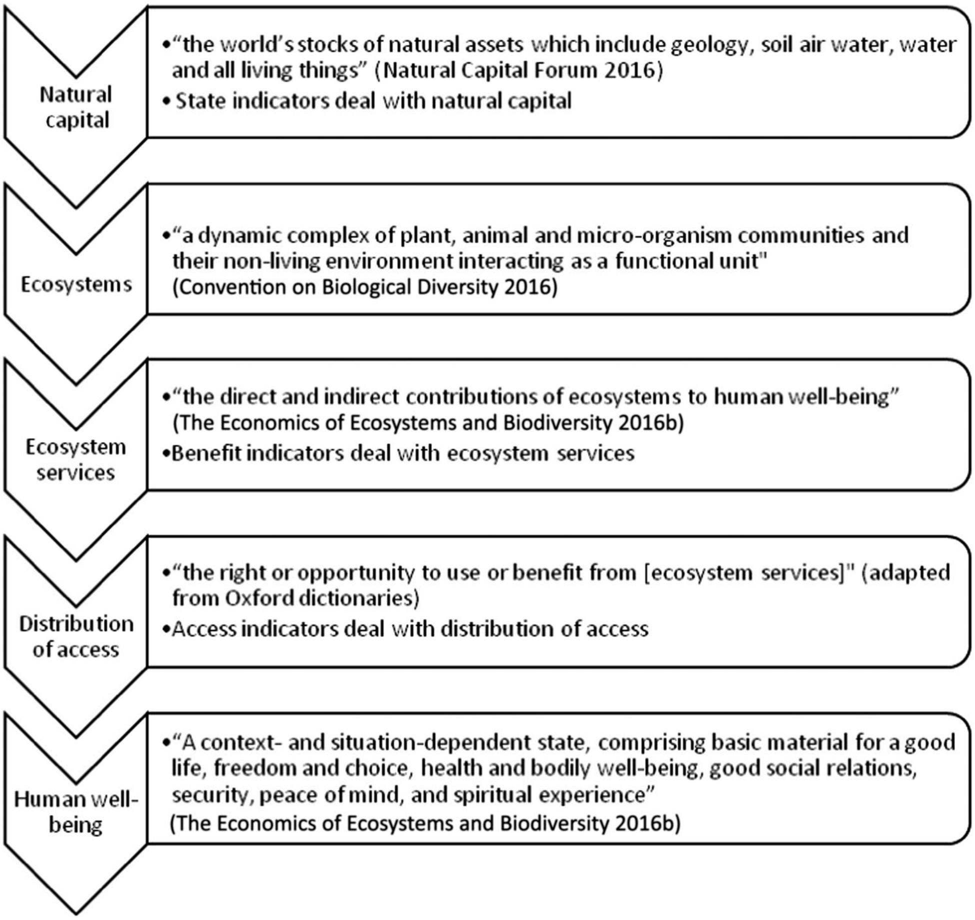

Figure 1 Basic flows from natural capital to human well-being (Convention on Biological Diversity 2016; Natural Capital Forum 2016; The Economics of Ecosystems and Biodiversity 2016b).

"moving away from the target" (i.e., ES were declining), while element two had "no significant overall progress." Both were given the lowest available level of confidence in the assessment "based on the available evidence" (Secretariat of the Convention on Biological Diversity 2014). Challenges in identifying indicators arise from the inherent complexity of ES: definitions of ES overlap (The Economics of Ecosystems and Biodiversity 2016a), for example, pollination also contributes to food provision; the same ES are provided in different ways in different areas; and the same NC can provide multiple ES. Trade-offs between ES are also important (Millennium Ecosystem Assessment 2005). For example, deforestation for agriculture may increase food provision at the expense of climate regulation and carbon storage (Coe *et al.* 2013).

Recent analysis for the Ad Hoc Technical Expert Group on Indicators for the Strategic Plan found that the set of available indicators for Target 14 was inadequate (Chenery *et al.* 2015). We address the challenges of availability of NC and ES datasets, and of assessment of progress toward Target 14. We identify relevant datasets, select an indicator set, and assess their trends to provide a preliminary evaluation of progress toward Target 14.

Methods

Step 1: Essential ES

As Target 14 focuses on "essential services," our first step was to define essential ES. For each ES defined by the Economics of Ecosystems and Biodiversity (The Economics of Ecosystems and Biodiversity 2010), we assessed its contribution to the components of three human well-being frameworks (Millennium Ecosystem Assessment 2003; Gough 2014; United Nations Development Programme 2015). These were selected for their differing approaches to defining well-being, to ensure we took a broad perspective. As Target 14 also focuses on local communities, we considered an ES "essential" if it contributed directly to well-being under any of these frameworks, while acknowledging that other ES are indirectly essential (e.g., climate regulation). Analysis of the Aichi Targets suggested that indirect ES were covered by other targets (e.g., "carbon sequestration" is covered by Target 15 [carbon stocks]). To focus on ES which would otherwise not be measured, indirect ES were excluded from our analysis (Table S1).

Step 2: Dataset compilation

We compiled an extensive list of datasets. While the majority of these did not meet our criteria for a Target 14 indicator set, we believe that this collection of datasets is a valuable contribution in itself. For element 1 of Target 14 (ecosystems are restored and safeguarded), we sought global datasets that could indicate trends in the state of NC underpinning each essential ES, and in the total benefits derived from those ES. For element 2 (accounting for the needs of vulnerable groups), we sought global datasets that could indicate trends in the distribution of access to those benefits across the human population (Tables S2 and S3). Although this approach does not explicitly consider the different groups mentioned in Target 14, people without sufficient access to essential ES are likely to be those considered to be poor and vulnerable.

We reviewed the literature and contacted experts to identify existing datasets, ongoing projects, and unpublished datasets (Tables S2 and S3). We excluded certain abiotic NC components such as fossil fuels and metals from this review (United Nations Environment Programme 2012). While we recognize that this excludes sources of energy, fertilizers, and raw materials, this is only after extensive processing using human capital and in combination with other NC; therefore, we believe that they are not the intended focus of Target 14. NC datasets were categorized as biodiversity, carbon, atmosphere, land, oceans, soil, and freshwater (Tables S2 and S3).

Step 3: Target 14 indicator set

Datasets were selected for each essential ES in three categories: (1) **state** of the underlying NC (which underpins the long-term sustainability of ES), (2) global **benefits** derived from the ES (measuring the status of element 1 of the Target), and (3) distribution of **access** to those benefits (measuring the status of element 2). Figure 1 shows how these categories map onto the flows from NC to human well-being.

Datasets that did not fit into these categories were rejected, as were datasets that were not from a credible source (scientific publications or institutionally branded reports or datasets). Datasets scoring "poor" in the following three criteria were also rejected: (1) spatial extent, (2) number of data points in time series, and (3) ability to detect trends in the ES or underlying NC. Additional criteria were: (4) date range, (5) likely continuation of data collection, and (6) data available online (Table S4). This includes all criteria for global biodiversity indicators considered by Tittensor *et al.* (2014) and Chenery *et al.* (2015), plus additional criteria recommended by the BIP (Biodiversity Indicators Partnership 2012). There are other criteria for environmental indicators (e.g., the Organisation for Economic Co-operation and Development list in Ruffing [2007]), however, we considered these the minimum criteria for a functional global-scale indicator, which could realistically be met by some of the available datasets.

Some datasets relate to multiple ES, for example, the "Wetlands Extent Index" could be a state indicator for "moderation of extreme events" as well as "waste-water processing." To avoid overweighting any datasets when interpreting our indicator set, we included each dataset only once. Those that relate to more than one ES are shown against the most relevant ES. To minimize gaps in our indicator set, in some cases, we selected datasets with a moderate relationship to the ES. We did this only where no stronger eligible datasets were identified, and highlight these indicators as particularly in need of improvement (Table S5).

Step 4: Analysis of trends

To identify trends over time, we calculated linear regressions of annual global averages for the selected datasets. Although actual trends may not be linear, Target 14 is concerned with the long-term trajectory rather than the dynamics of interannual change. Linear regression is the simplest approach to identifying an overall long-term trend, particularly as there is significant uncertainty within the data, as many datasets selected are necessarily based to some extent on estimates. For two of our selected datasets, countries were excluded from our analysis if they had data missing for any year, to ensure we compared like with like when calculating trends. Sensitivity analysis shows that this approach did not materially affect our results (Annex S2). A linear regression with P-value ≤ 0.05 was considered to indicate a statistically significant trend. All available years from 1980 onward were included in the analysis for each dataset, to identify reasonably long-term trends.

For one dataset, "disability adjusted life years (DALYs) lost to parasitic and vector-borne diseases," data were only available for 2000 and 2012. To be precautionary about inferring trends given the lack of data, we considered a change of over 20% between the two years to be substantive. For seven datasets, we relied on previously published analyses to determine trends (Table S6). We define a positive trend as one that results in an increase in well-being, regardless of the direction of the statistical trend.

To derive overall ratings for each ES, if all selected indicators for that ES had the same trend (positive, negative, or no trend), a matching overall rating was given. If the indicators were a combination of positive trend and no trend, an overall rating of positive trend was given (similarly for negative trend). If an ES had indicators showing both positive and negative trends, an ambiguous overall rating was given.

Baseline states against which to assess performance have not been identified, a limitation raised by Tittensor *et al.* (2014). Therefore, our analysis does not indicate proximity to meeting Target 14, only whether the gap is closing or widening.

Results

We classified 13 of the ES defined by TEEB as "essential" in the context of Target 14 (Table S1). In total, we identified 153 datasets (Tables S2 and S3). Most have global coverage, with nine regional datasets included that are useful for global analyses. For example, Saatchi *et al.* (2011) provide globally important information about forest carbon stocks in tropical regions.

From these datasets, we selected a set of 21 indicators (Tables 1 and S3). Annex S1 describes the selection process for each ES. Gaps remain in our indicator set, in particular no suitable datasets were identified for "aesthetic appreciation and inspiration" or "spiritual experience and sense of place" (Table S5).

Of these 21 datasets, we assessed 13 as having high ability to detect trends in the ES or underlying NC. All selected datasets have global coverage. The four "extreme events" datasets have the longest complete time series, with annual data from 1980 to 2014. In contrast, two of the selected datasets have just two or three data points in the time series. Additionally, five of the selected datasets ended before 2011, whereas nine had a value for 2014 or 2015 (Table S4).

Six of the seven state indicators had a negative trend. The other, "mangrove extent," had no trend. Thus, overall, analysis of our indicator set suggests that the state of the NC underpinning ES is declining. Of the 10 benefit indicators, six show a positive trend, two have a negative trend, and the trends for two are ambiguous, depending on the time period over which they are analyzed (Figure 2). Thus, overall, the benefits obtained from ES appear to be improving, although this conclusion hides substantial variation. "Prevalence of undernourishment" has a positive (decreasing) trend, "population affected by fires, floods and storms" has a negative (increasing) trend, and the other two access indicators have no discernible trend, indicating no overall improvement in access to ES among the poor and vulnerable (Tables 2 and S6).

Overall trends (Table 2) were positive for two ES ("biological control" and "recreation and physical and mental health"), ambiguous for six, and negative for three ("freshwater," "waste-water treatment," and "erosion prevention and soil fertility"), suggesting little or no progress toward Target 14. This broadly confirms the GBO-4 assessment (Secretariat of the Convention on Biological Diversity 2014). Of the 16 linear regressions calculated, six had an $R^2 \geq 0.9$, indicating strong trends with little variation, while others had relatively noisy datasets, and three showed no trend (Figure 3; Table S6).

Discussion

Our approach captures the essence of Target 14, by focusing on the state of the NC that underpins essential ES, together with the benefits derived from them, and the distribution of access to those benefits. However, the Target explicitly mentions livelihoods, and access to ES for specific vulnerable groups. These components are hard to include in a global-scale indicator set, as that requires large amounts of disaggregated local-scale data.

Our proposed set of 21 indicators is more comprehensive than those used previously for Target 14. GBO-4 used just six indicators alongside a selection of case studies (Secretariat of the Convention on Biological Diversity 2014). Tittensor *et al.* (2014) identified just one indicator that met their criteria for analysis, "the Red List Index for pollinators," which we included in our set. Tittensor *et al.* considered and rejected eight datasets for Target 14, of which three are included in our indicator set: "inland water resources" was rejected on the grounds of geographic coverage, although our dataset "total inland water resources per capita" covers 180 countries over five continents. "Production of forest products" and "inadequate access to food" were rejected by Tittensor *et al.* on the grounds of relevance to the target, but both fitted well into the categories of indicators we sought. Tittensor *et al.* did not set out any structure within which to identify datasets, making it difficult to assess relevance.

Currently, global indicators for ES and NC are inadequate for detailed trend analysis, highlighting an important challenge for all the Aichi Targets. Our work also demonstrates potential difficulties for the measurement

Table 1 State, benefit, and access indicators selected for the Target 14 assessment, organized by ecosystem service (for details, see Table S2)

Ecosystem service	State indicators	Benefit indicators	Access indicators
Provisioning services:			
Food	S1. State of world marine fish stocks	B1. Average dietary energy supply adequacy	A1. Prevalence of undernourishment
Raw materials	S2. Forest extent	B2. Production of forest products	–
Freshwater	S3. Nitrogen and phosphate fertilizers	B3. Renewable water resources per capita	–
Medicinal resources	S4. Red List Index (RLI) for food and medicine	B4. Estimated export volumes of medicinal plants	–
Regulating services:			
Local climate and air quality	–	B5. Population weighted exposure to particulate matter <2.5 μm in width ($PM_{2.5}$)	A2. Proportion of the population exposed to a $PM_{2.5}$ concentration of 10 $\mu g/m^3$
Moderation of extreme events	S5. Mangroves extent	B6. Occurrence of fires, floods, and storms	A3. Population affected by fires, floods, and storms
Waste–water treatment	S6. Wetlands Extent Index	–	–
Erosion prevention and soil fertility	–	B7. Occurrence of drought and landslides	A4. Population affected by drought and landslides
Pollination	S7. RLI for: pollinators	B8. Production of pollinator–dependent crops	–
Biological control	–	B9. Disability adjusted life years (DALYs) lost to parasitic and vector diseases	–
Cultural services:			
Recreation and physical and mental health	–	B10. Global average healthy life expectancy (HALE)	–
Aesthetic appreciation and inspiration	–	–	–
Spiritual experience and sense of place	–	–	–

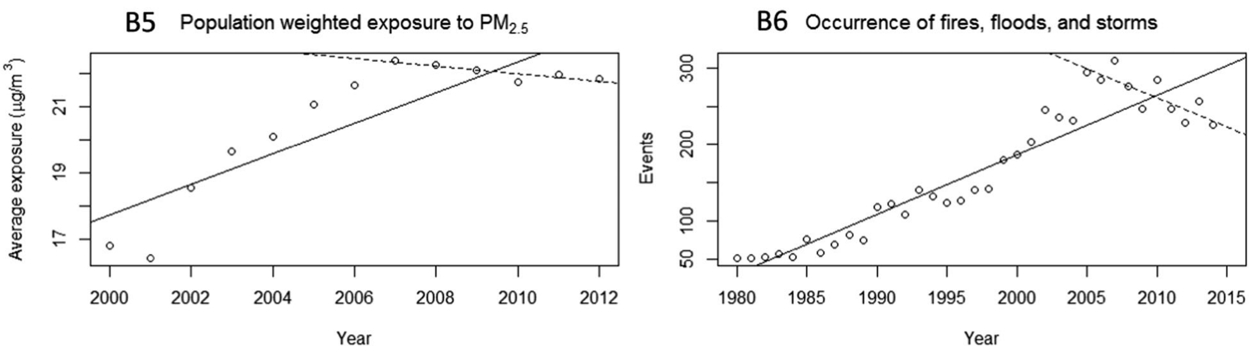

Figure 2 Trends in indicators showing reversed trends depending on the time periods analyzed. Solid lines show the regression line for the whole time series and dashed lines show the regression line for a subset of the time series ending at the final available data point: 2007–2012 for B5; 2005–2014 for B6. For full details of data sources and analysis, see Tables S2 and S6.

Table 2 Results of analysis organized by ecosystem service (for full analysis of datasets, see Tables S5 and S6)

Ecosystem service	State	Benefit	Access	Overall
Provisioning services:				
Food	↘	↗	↗	(↘↗)
Raw materials	↘	↗	–	(↘↗)
Fresh water	↘	↘	–	↘
Medicinal resources	↘	↗	–	(↘↗)
Regulating services:				
Local climate and air quality	–	(↘↗)	→	(↘↗)
Moderation of extreme events	→	(↘↗)	↘	(↘↗)
Waste–water treatment	↘	–	–	↘
Erosion prevention and soil fertility	–	↘	→	↘
Pollination	↘	↗	–	(↘↗)
Biological control	–	↗	–	↗
Cultural services:				
Recreation and physical and mental health	–	↗	–	↗
Aesthetic appreciation and inspiration	–	–	–	–
Spiritual experience and sense of place	–	–	–	–

↗ positive trend; ↘ negative trend; → no trend; (↘↗) trend ambiguous;—no indicators identified.

of progress against some of the Sustainable Development Goals (SDGs; United Nations Department of Economic and Social Affairs 2015). Series length and series fullness (i.e., how many years have data within the series length), and the interaction of these, impact the analysis of overall trends in time series data (Collen *et al.* 2009). There was great variability in these aspects for our indicator set. The approach taken by Tittensor *et al.* (2014), to fit statistical models and forecast levels at 2020, would provide a more powerful analysis, but given levels of uncertainty in the selected datasets, and the variability in series length and fullness, we preferred a simpler approach. Future researchers may consider establishing appropriate benchmarks or thresholds for each indicator, to assess proximity to meeting Target 14 as well as overall trends.

Gaps remain in our indicator set, particularly for cultural services, for which only one dataset was selected (Table S5). Development of new methods for assessing cultural ES would be beneficial, for example, UN Habitat have proposed an SDG indicator, “Proportion of residents within 0.5km of accessible green and public space,” based on existing remote sensing data. No suitable datasets were identified for 18 of the 39 categories for which we sought indicators. Furthermore, only 13 (62%) of our selected indicators have a strong ability to detect trends in the relevant ES or underlying NC. Data on the state of NC are particularly important to provide information on the sustainability of ES for future generations (Millennium Ecosystem Assessment 2005). The state indicators for “freshwater,” “medicinal resources,” and “pollination” were all assessed as only moderately able to detect trends in the underlying NC, and no suitable state indicators were identified for “local climate and air quality,” “erosion prevention and soil fertility,” “biological control,” or any cultural ES. Additionally, no suitable state indicators were identified for food grown on the land. Developing datasets to monitor the state of the NC underlying these ES should be the focus of further work. Some of these gaps are being addressed through initiatives including the Water Quality Index for Biodiversity (United Nations Environment Programme 2015) and the Global Action on Pollination Services for Sustainable Agriculture (Food and Agriculture Organization of the United Nations 2015). However, it will take time to generate sufficient data to identify trends, and resources for generating data will only be made available where there is clear utility from delivering results (Bubb *et al.* 2011).

For transparency, we show the results of analysis of each dataset individually (Table 2). To avoid opposing trends canceling each other out, we use an “ambiguous” overall ES rating in these cases. In assessing progress toward Target 14, we give all datasets equal weighting regardless of the strength of their ability to reflect relevant trends or their relative importance to ES. Some of these indicators might have more importance than others for global ES, potentially adding bias.

Positive trends can be seen in benefits, at least in the short term, even where the underlying NC is being degraded. For example, the energy supply to the urban poor can be improved by clearing forests and making charcoal for cooking fuel. In contrast, all but one of our state indicators has a negative trend, suggesting that benefits are being extracted today at the expense of future generations.

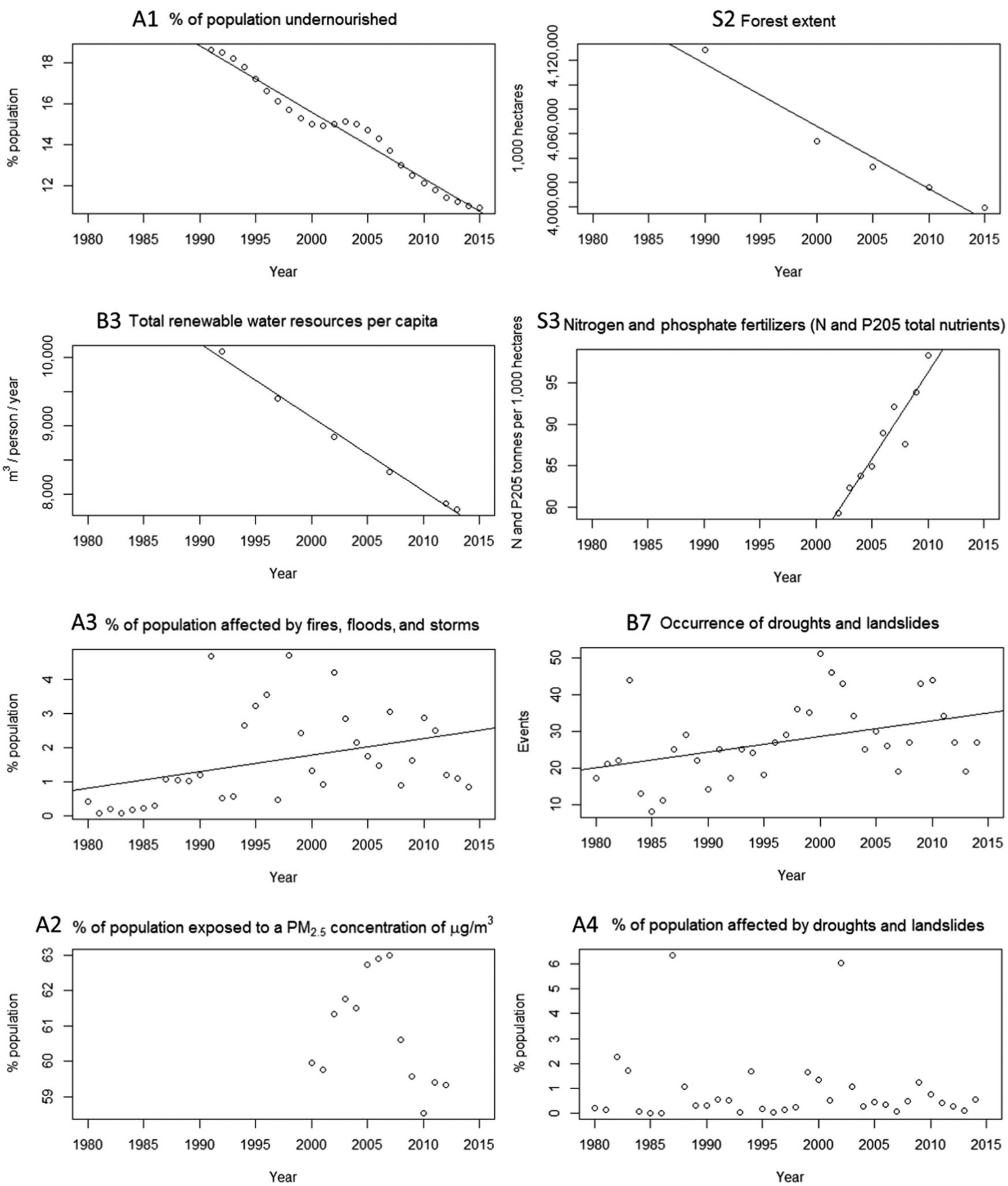

Figure 3 Examples of trends in indicators of relevance to Aichi Biodiversity Target 14 (for full details of data sources and analysis, see Tables S2 and S6).

In general, positive trends were identified in areas important for human development (e.g., access to sufficient food), which can be generated from human capital and infrastructure and are not solely dependent on the state of the underlying NC. Negative trends were found in areas with less immediate influence on well-being, such as "erosion prevention and soil fertility," suggesting that NC providing such benefits is at particular risk. Less easily quantified ES such as "sense of place" may also be more difficult to replace in the absence of the NC that underpins them.

In conclusion, determining a structure against which to identify datasets enabled selection of a more complete indicator set than previously used to assess progress toward Target 14. Our analysis supports previous conclusions that the global community is not making any real progress toward Target 14. The pattern of trends within our indicator set highlights the "environmentalist's paradox," that human well-being is increasing, together with access to ES including freshwater and disease prevention, despite the degradation of the NC that underpins those ES. Negative trends in ES such as "moderation of extreme events" highlight the risk that the paradox may not hold true forever. An increased ability to monitor the interactions between human well-being, ES, and NC is needed, to support the generation of policy options and their testing within an indicator-policy cycle (Nicholson *et al.* 2012), supporting a move toward a more sustainable future.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Table S1: Determination of "essential" ecosystem services (ES). We identified essential ES by assessing the likely contribution to well-being of each ES categorized by The Economics of Ecosystems and Biodiversity (The Economics of Ecosystems and Biodiversity 2016). To ensure that we took a broad perspective, we considered contribution to well-being in terms of the components of three different human well-being frameworks as outlined in columns 2–4 in the table below.

Table S2: Target 14 indicator set, comprised of state, benefit, and access datasets, identified through literature review and contact with experts. "State" datasets are grouped into seven categories of natural capital (NC): biodiversity (including species biodiversity and stocks, genetic resources, and ecological communities); carbon (including Net Primary Productivity, soil organic carbon, and ocean carbon); atmosphere (including precipitation, temperature, and air quality); land; oceans; soil (including fertility and productivity); and freshwater (including quality, extent, and rivers). "Benefit" and "access" datasets are categorized by the most relevant ES.

Our categories of NC are based on the categories proposed by the Natural Capital Committee (2014), adapted to better fit the scope of our review. We combined "species" and "ecological communities" into "biodiversity," included "coasts" within our "oceans" category, and excluded "minerals" and "subsoil assets" as these datasets were not a focus of our study, with the exception of "carbon" which we added as a separate category.

Table S3: Additional state, benefit, and access datasets, identified through literature review and contact with experts. "State" datasets are grouped into seven categories of natural capital: biodiversity (including species biodiversity and stocks, genetic resources, and ecological communities); carbon (including Net Primary Productivity, soil organic carbon, and ocean carbon); atmosphere (including precipitation, temperature, and air quality); land; oceans; soil (including fertility and productivity); and freshwater (including quality, extent, and rivers). "Benefit" and "access" datasets are categorized by ecosystem service.

Table S4: Assessment of selected Target 14 indicators.

a) Spatial extent: rated poor if extent is fewer than 10 countries or fewer than three continents; rated good if range covers at least five continents and at least 20 countries (Chenery *et al.* 2015);

b) Number of data points in the time series: rated moderate if two to four data points available, rated high if five or more data points available;

c) Rated high if end point is 2014 or 2015, rated poor if end point is 2010 or earlier.

Table S5: Key data gaps in our indicator set by indicator category and ES. We highlight where no datasets were identified, and where the best available datasets were assessed as "poor" in any of our assessment criteria (Table S4). These indicators are particularly in need of better, or extended, datasets in the future.

Table S6: Analysis of our Target 14 indicator set. Results of linear regressions to estimate trends in selected Target 14 indicators, for all selected indicators with accessible data and at least three data points in the time series. For all other indicators, we have summarized the analysis completed.

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